End-to-End Trade-space Analysis for Designing Constellation *(Tradespace Analysis Tool for Constellations, TAT-C)*

Jacqueline Le Moigne, Philip Dabney, Veronica Foreman, Paul T. Grogan, Sigfried Hache, Matthew Holland, Steven Hughes, Sreeja Nag, Afreen Siddiqi

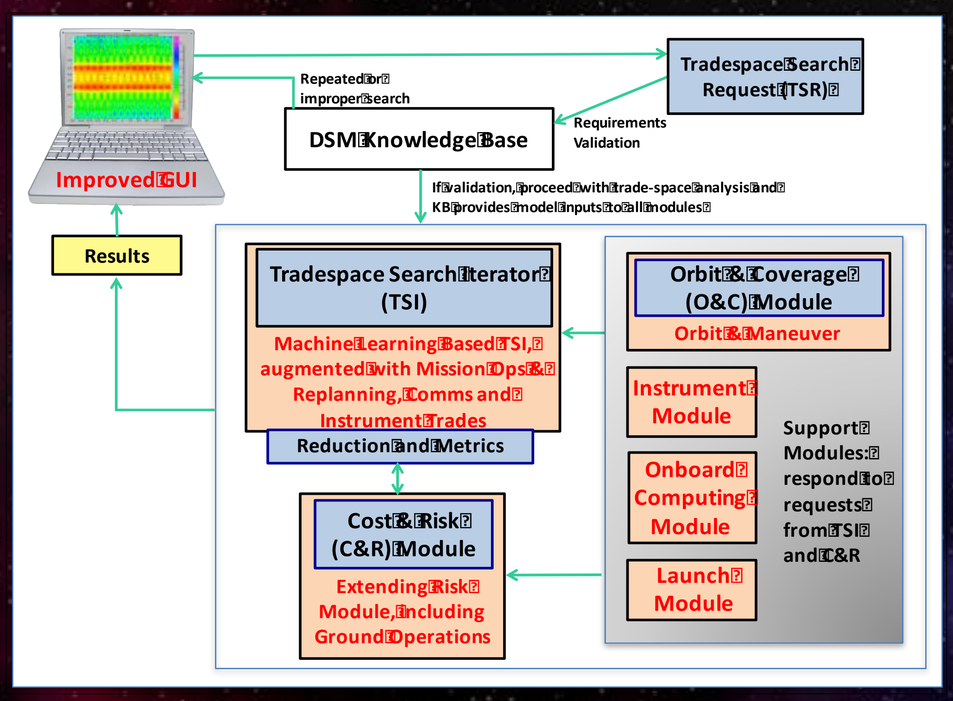
NASA Goddard Space Flight Center, MIT, Cornell Univ., Stevens Inst. of Tech, BAER Institute

A *Distributed Spacecraft Mission (DSM)* is a mission that involves multiple spacecraft to achieve one or more *common* goals

A *Constellation* is a space mission that, beginning with its inception, is composed of two or more spacecraft that are placed into specific orbit(s) for the purpose of serving a common objective (e.g., Iridium)

OBJECTIVES

- Extend TAT-C Capabilities, *i.e.*, increase the dimension of the trade-space with:
  - Various trajectories, orbital planes, mission replanning, orbit and Maneuver Modeling, etc.
  - New trade modules (instrument, launch, onboard computing, etc.)
- Optimize the Trade-Space Exploration by Utilizing Machine Learning and a Fully Functional Knowledge Base (KB) to Efficiently Traverse a Large Trade-Space



APPROACH

- Include Mission Ops in Cost Module; Develop TAT-C ML / GMAT Interface; Develop Figures of Merit (FOM) for Mission Replanning
- Include Occultors, Lidars and Bi-Static Radars; Develop New Launch Module; Leverage AIST14/French results for Onboard Proc. Trades
- Develop KB via semantic web technologies, formal knowledge representations and related taxonomies
- Machine Learning using Adaptive Operator Selection strategies (AOS) and Knowledge-Driven Optimization (KDO)
- Improve GUI and interfaces to OSSEs and MBSE

SCIENCE REQUIREMENTS - INPUTS

- Mission Concept (Start epoch, Area of interest, etc.)
- Satellite Specs (Number of Sats, Types, Altitudes, etc.)
- Payload Specs (Type, Mass, Volume, Power, etc.)

SCIENCE REQUIREMENTS - OUTPUTS

- Spatial Metrics (spatial res, swath, imahe overlap, coverage, etc.)
- Temporal Metrics (occultation time, %period time in sun, repeat & revisit times, etc.)
- Angular Metrics (zenith and azimuth angles, solar zenith and azimuth angles, etc.)
- Radiometric Metrics (signal to noise ratio, etc.)

KNOWLEDGE BASE

- Centralized store of structured data readable by humans and machines
- Support all TAT-C tasks:
  - Analysis: compose new mission concepts from existing model inputs
  - Exploration: discover new mission concepts by querying previous results
- Layered client-server architecture over HTTP

TRADESPACE SEARCH ITERATOR (TSI)

- TSI reads user inputs given to the GUI to create iterator inputs (JSON files). Uses default values from Landsat 8 (w/ ETM+ payload) if no inputs
- TSI generates DSM architectures for a combination of variable values that satisfy iterator inputs
- A DSM architecture is a unique combination of variable values (altitude, inclination, FOV, number of satellites, etc.)
- For each arch, TSI creates files and sends commands to module 'Reduction & Metrics' to compute architecture performance and to module 'Cost and Risk' to compute architecture cost

REDUCTION & METRICS MODULE

- Reduction & Metrics is responsible for calling module 'Orbits & Coverage' to propagate the orbit of every sat and compute coverage given payload specs.
- Reduction & Metrics integrates coverage and computes all performance metrics.

ORBIT & COVERAGE MODULE

- Model orbits balancing accuracy and performance
- Compute coverage metrics for constellation/sensor set
- Compute ancillary orbit data for performance, cost, and risk

COST & RISK MODULE

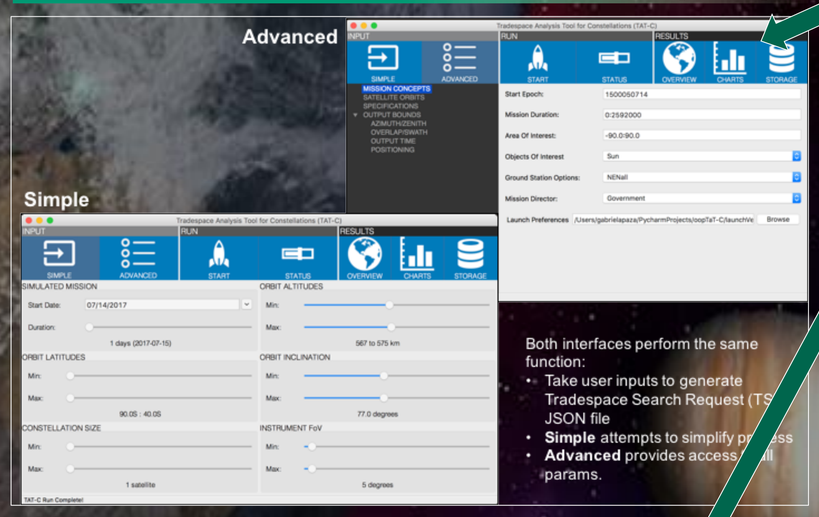
COST:

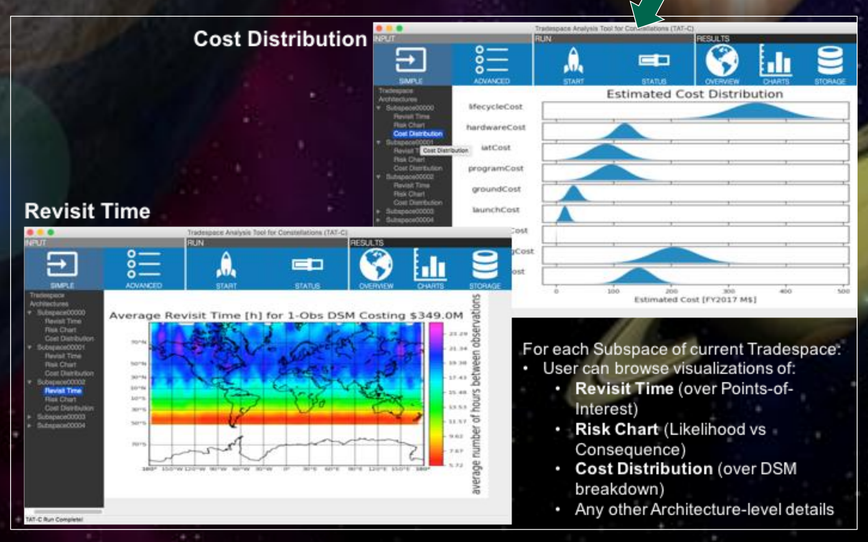
- Improve on limitations of existing models w/r to constellations
- Aggregate model consisting of Cost Estimating Relationships (CERs) from widely accepted, publically available models
- Output: Probability density function showing most likely cost for mission lifecycle + selected mission components, including recurring, non-recurring, spacecraft bus, and payload

RISK:

- Quasi-quantitative fever chart approach applied to assess 15 system and subsystem risks
- Fever chart output selected for visualization clarity and appropriateness for pre-Phase A risk assessment

GRAPHICAL USER INTERFACE (GUI)





CURRENT ACCOMPLISHMENTS

- Definition Requirements
- Architecture and Overall Control Flow
- Current version (implemented in C++ and Python):
  - Modules: Tradespace Search Iterator (TSI), Reduction and Metrics (R&M), Orbit and Coverage (O&C), Cost and Risk (C&R) Assessment, Functioning Knowledge Base (KB)
  - Homogeneous and heterogeneous, ad-hoc and precessing constellations
  - Fully functional Graphical User Interface (GUI) and prototype OSSE interface
  - Validation using Sustainable Land Imaging (SLI)

The authors wish to acknowledge the support of NASA Earth Science Technology Office (ESTO) Advanced Information Systems Technology (AIST) Program under NRA-NNH14ZDA001N-AIST.